On the Origin of the Multiplicity Fluctuations in High Energy Heavy Ion Collisions

G.V.Danilov and E.V. Shuryak

State University of New York, Stony Brook, NY 11794, USA

Multiplicity fluctuations in heavy ion collisions obtain comparable contributions both from initial stage of the collisions, and from final stage interaction. We calculate the former component, using the "wounded nucleon" model and standard assumptions about nuclei and NN cross section. Combining it with the second one, calculated previously by Stephanov,Rajagopal and Shuryak, ref.2, we obtain good quantitative description of experimental data (ref.3) from NA49 collaboration at CERN on central PbPb collisions.

I. INTRODUCTION

Recently the subject of event-by-event fluctuations have attracted a significant interest. On the theory side, it was motivated by possible relation with thermodynamical observables [1] toward understanding, or as a background to critical fluctuations, expected at the so called tricritical point [2]. Experimentally, it was obviously stimulated by near-perfect Gaussian shapes of distribution observed by NA49 experiment at CERN [4].

As emphasized in ref. [3], all observables can be divided into two broad classes: "intensive" (e.g. mean energy or p_t per particle, and "extensive" (e.g. total particle multiplicity) ones. The latter are sensitive not only to $final-state$ interaction effects like resonance production (discussed in detail in [3]) but also to the $initial-state$ effects: on general grounds their contributions can be comparable. The simplest of non-statistical effects is generated by pure geometry of the collision. the distribution over impact parameter b in a range between 0 and some b_{max} (depending on trigger conditions). This particular effect recently discussed by Baym and Heiselberg [5], with the conclusion that it can account for the observed multiplicity fluctuations. The aim of this brief paper is to re-consider this calculation, and also include other non-statistical fluctuations originating at the initial stage.

The central quantity to be discussed is the following ratio

$$\frac{< \Delta N_{ch}^2 >}{< N_{ch} >} \approx 2.0 - 2.2 \tag{1}$$

where the r.h.s. is the NA49 value for 5% centrality data to be used in this work. If secondary particle production be purely independent process govern by a Poisson distribution, the r.h.s. would be 1. Correlations coming from resonant decays estimated in [3] lead to a value of about 1.5. The main question addressed in this work is whether fluctuations in the initial collision do or do not explain the remaining part of the dispersion.

II. THE MODEL

We discuss three sources of the initial-state fluctuations: (i) the range of impact parameters b as already mentioned; (ii) fluctuations in the number of participants due to *punched through "spectators"*; (iii) fluctuations of the individual nucleons, or of the NN cross section [6].

Nuclear distributions are parameterized as usual

$$n(r) = \frac{n_0}{exp[(r-R)/a]+1} \tag{2}$$

with usual parameters for Pb, $n_0 = .17 fm^{-3}$ R=6.52 fm, a=0.53 fm. As we see below, the non-zero a is important for the (ii) component. The probability for a nucleon to go through and become spectator is the usual eikonal-type $exp(-\sigma_{NN}\int_{path} dz\, n(z))$ formula. We used both the mean σ_{NN}, or a fluctuating one*. In the latter case we use normal distribution, with the value of the dispersion taken from Fig.1 of [6]. For collision energy $E \sim 100 GeV$ it is $\Delta\sigma_{NN} \approx .5 < \sigma_{NN} >$. We attribute $1/\sqrt{2}$ part of this dispersion to each nucleon, as they obviously fluctuate independently before collision.

We have simulated PbPb collisions and b interval corresponding to 5% of the total cross section: the resulting distribution of the number of participants N_{part} is shown in Fig.1. Our main result (all effects included) is shown by the closed points: for comparison we have also plotted 3 other variants. If fluctuations of the cross section is switched off, we get the distribution shown by open points. Although its shape is similar, there is an overall shift to the maximal N_{part}: if nucleons do not fluctuate, it is more difficult to punch through. Similar thing happens if the surface thickness a is put to zero (the solid line). However purely geometric "triangular" distribution over b, from 0 to its maximum, have a different shape and width: it is this naive distribution which was used in [5]. (We have found that for larger centrality cut our results converge toward geometric one, but for small 5% cut it is clearly inadequate.)

*We remind the reader that at high energies we consider, the nucleon has no time to reconfigure, and so all subsequent interactions of one nucleon take place with the same cross section.

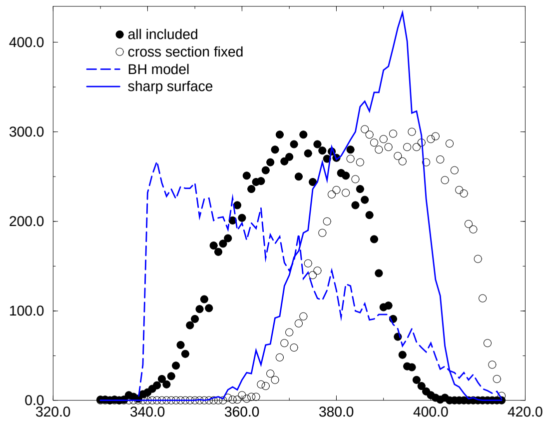

FIG. 1. Distribution over the number of participants including all effects (closed points), without fluctuations in the NN cross section (open ones). Solid line shows what happens for nuclei without diffuse surface layer (a=0 in eq.(1)), while the dashed line shows the distribution resulting from impact parameter variation, as used in [5]

III. RESULTS

Convoluting the distribution of the number of participants obtained above with the contribution of the $final-state$ interaction effects, we get the final distribution over the observed number of charged particles N_{ch}:

$$\frac{dN}{dN_{ch}} = \int \frac{dN_{part}P(N_{part})}{(2\pi)^{1/2}\Delta N_{ch}(N_{part})} e^{-\frac{[N_{ch}-<N_{ch}(N_{part})>]^2}{2*\Delta N_{ch}(N_{part})^2}} \quad (3)$$

where the mean and dispersion are assumed to depend linearly on the number of participants N_{part}. In particular, we use

$$< N_{ch}(N_{part}) >= CN_{part} \quad (4)$$

(with C determined from the mean observed multiplicity to be C=.75). For the dispersion we use the estimated effect of final state interaction in resonance gas [3], namely

$$\Delta N_{ch}(N_{part})^2 = 1.5 < N_{ch}(N_{part}) > \quad (5)$$

The results are shown in Fig.2. One can see that the distribution we obtain reproduces data rather well, although it is somewhat more narrow. Let us also note, that because it is only the width of the N_{part} matters, other model distributions shown in Fig.1 do equally well. The exception is the triangular one: due to its larger width it is closer to data than ours. (This explains why the authors of [5] obtained good agreement in their total width, but of course does not justify it.)

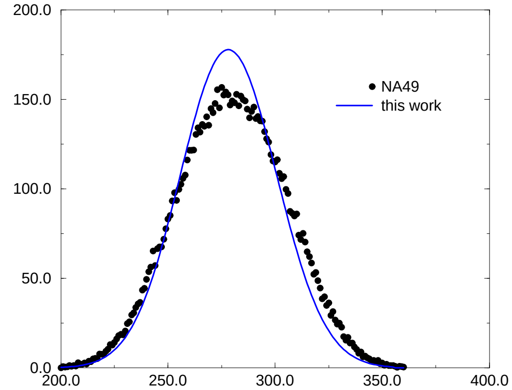

FIG. 2. The calculated multiplicity distribution from our model (solid line) is compared to the observed one (points).

IV. SUMMARY, DISCUSSION AND OUTLOOK

In summary, we have found that initial-state fluctuations contribute about 20% to the ratio (1), to be compared to 50% from random statistics and another 25% from final state (resonance) correlations [3]. In sum, they do indeed explain data at about 10% level, which is we think is their accuracy level. Further progress would need much more work, including studies of the detector acceptance, etc.

The main physics conclusion is that out of three effects listed at the beginning of section 2 the dominant one is clearly (ii), namely the fluctuations in a number of punched-through spectators. In contrast to [5], we do not find that purely geometrical effect (i) is important for this particular data. We also found fluctuations in the NN cross section (iii) to be relatively unimportant for the width of final distribution, adding only few percent to it.

As a discussion item, one may consider remaining discrepancy between data and our calculation. Even more than the width, one may address the origin of the asymmetry of the multiplicity distribution, well seen in Fig.2: the right tail is larger than the left. However, before ascribing to this small change of width and/or small asymmetry any physical significance, the issue of acceptance should be better addressed.

For outlook, let us show that with the increasing multiplicity expected at RHIC/LHC (both because of larger multiplicity and larger detector coverage) the role of the initial-state fluctuations *increases*. The ratio (1) is constructed in such a way that statistical fluctuations always produce the same r.h.s at any multiplicity. However, non-statistical ones we discuss do not obey it. For example, if we assume the same collision but (quite arbitrarily) that the mean observed number of particles is 1000 (which means C=2.7 in (4)) we get from the exactly same calculation

$$\frac{< \Delta N_{ch}^2 >}{< N_{ch} >} \approx 2.57 \qquad (6)$$

to be compared with the the value about 1.9 above.

V. ACKNOWLEDGMENTS

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